Differential optical remoting of ultrafast charge packets using self-linearized modulation

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Abstract: We demonstrate conversion of ultrafast input analog charge packets into a differential optical signal, using quantum-well self-electrooptic effect devices in a novel self-linearized mode of operation.

In certain mixed-signal systems such as analog-to-digital converters (ADCs), carrying signals from one subsystem to another optically can yield important advantages. For example, one proposal for a 100 gigasample/second ADC calls for packets of charge that have been sampled on a capacitor by a high-speed sample-and-hold photoconductive switch to be relayed to a CMOS buffer and quantizer [1]. In such a case, optically remoting these charge packets could increase the noise immunity of the sample-and-hold subsystem from electronic noise. Optical remoting can also provide added flexibility if the ADC has multiple channels that must be interleaved, since quantizer circuits of different channels might then be placed on different chips to reduce crosstalk.

For this kind of A/D system then, a method for linear, high-speed electro-optic conversion is required. We have shown in the past the feasibility of doing so with a multiple quantum well (MQW) self electro-optic effect device (SEED), which converts charge packets into a single optical signal [2]. The conversion process is self-linearized due to an internal negative feedback loop, so that each electron's worth of input charge causes one photon to be absorbed by the device [3]. However, one disadvantage of operating with a single-ended output is the limited dynamic range of the input, since the electrical pulses must rise above a threshold amount of charge before linear conversion is attained. (This threshold is necessary to push the SEED into sufficient reverse bias.) In this work we demonstrate differential optical operation — the charge packets are converted into the *difference* of two optical beams. Differential operation is desirable since it mitigates common-mode noise that might for example be present on the laser source. This differential scheme also opens up the possibility of converting negative electrical signals, thus allowing for the conversion of input signals with a very high dynamic range.

The differential electro-optic converter consists of two SEED modulators (A and B) connected in series in a totem-pole fashion (Fig. 1). For the purpose of this experiment, the input charge packets are supplied by a third modulator (C), which is driven with mode-locked optical pulses that have a FWHM of approximately 150 fs.

All three modulators are p-i-n diodes with 50 pairs of 95Å GaAs wells and 30Å $Al_{0.3}Ga_{0.7}As$ barriers. The individual modulators are flip-chip bonded to a quartz wafer with a pattern of gold lines previously deposited. These gold lines connect the modulators in the desired configuration, and also provide contacts for external voltage supplies.

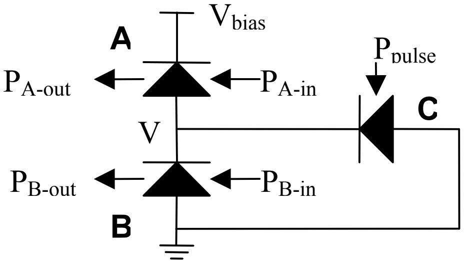

Fig. 1 SEEDs A and B in a totem pole structure perform linear differential electro-optic conversion. Input charge packets are provided by device C driven by short optical pulses.

Constant 859 nm beams with powers P_{A-in} and P_{B-in} are incident on devices A and B. These modulators are electrically biased at V_{bias} = 4V, and their optical absorption increases with electric field. For the results shown here, P_{A-in} = 0.43 mW and P_{B-in} = 0.83 mW. The powers were purposely set differently so that the power swings in P_{A-out} and P_{B-out} were approximately equal. In other applications however, the input powers would probably be set identically. Incidentally, note that with no incident light on device C, the photocurrents through A and B are equal. This is true even though P_{A-in} is less than P_{B-in}. In this particular case, an internal negative feedback loop lowers the voltage V below $V_{bias}/2$ so that the photocurrents through both devices become identical.

To begin the conversion process, the input charge packet is injected into the center node by exciting device C with a laser pulse. This packet of negative charge temporarily lowers the voltage V, so that the voltage bias on device A increases and the voltage bias on device B decreases. Relative to the situation just before the pulse excitation, A now absorbs more light while B absorbs less light. Consequently, the photocurrent through device A is now larger than that through device

B, which causes the voltage V to increase. Eventually, V returns to its initial state, and the device is ready to convert the next electrical pulse. The time constant of this recovery is given by

$$\tau = \hbar\omega C / \left(e\gamma P_{in}\right),$$

where C is the total capacitance at the center node, e is the charge of an electron, P_{in} is the total input CW power, and $\gamma = \partial A / \partial V$ is the absorption sensitivity with respect to voltage [4].

Figure 2 shows the difference in the powers of the output optical beams. Since this result was obtained by subtracting two beams with small swings on large DC backgrounds, the y-offset of the curve is subject to a large fractional error. The height of the peaks, however, is accurate to an experimental error of about 5%. The fitted time-constant of the device recovery is 3.5 ns. With our experimental conditions, a measured capacitance of 60 fF, and an absorption sensitivity of about 0.05 V^{-1}, the predicted time constant is on the order of nanoseconds and hence consistent with the measured result.

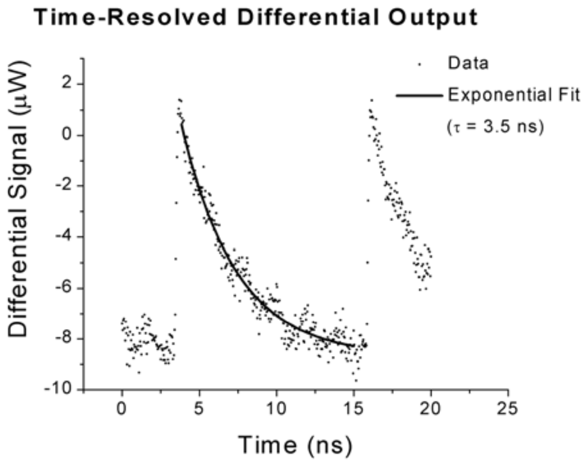

Fig. 2 The differential output signal rises initially when a current pulse is injected into the input node, then recovers back to its initial state. The current pulses occur at the 80 MHz repetition rate of the mode-locked laser.

We determine whether the electro-optic conversion is linear by varying the power of the pulsed laser driving device C. This has the effect of changing the amount of charge in the charge packet injected into the center node. By measuring the average current flowing through the power supply providing V_{bias}, we can deduce the amount of charge in each charge packet. We also measure the transmitted power through devices A and B with a high-speed photodetector and oscilloscope, and then calculate the difference of the average powers. The result is shown in Fig. 3, where a linear relationship is evident. Two features are worth noting. First, the slope of the line is close to unity, as expected for 100% internal quantum efficiency. Also, the last data point indicates that at the highest charge injection, fewer photons are present in the signal than anticipated. This is because for that specific case, so much charge has been injected into the center node that device A has reached a flat portion of the electroabsorption curve. Since the absorption sensitivity is low here, the device slows down and cannot complete the electro-optic conversion process within the repetition period of the input charge pulses.

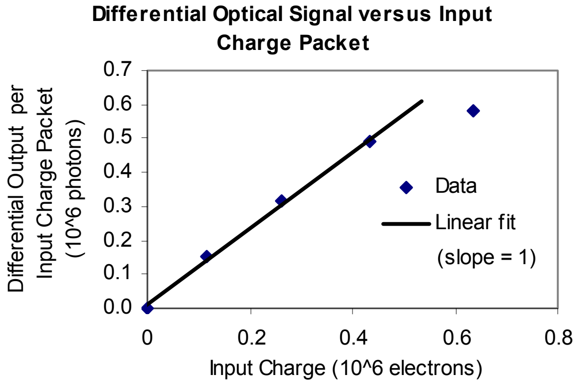

Fig. 3 The differential optical output is linearly proportional to the input electrical charge. The constant of proportionality indicates unity quantum efficiency.

In summary, we have demonstrated the concept of electro-optic conversion of pulsed currents into a differential optical signal, using self-linearized MQW SEED modulators. The measured time constant is in agreement with approximate calculations using a simple first-order model. We have also shown that the electro-optic conversion is linear, even though the input signal is of a much higher bandwidth than the modulator itself. Hence, this device holds great promise for high-sensitivity electronic systems such as analog-to-digital converters.

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